NAM NGUM 3 HYDROPOWER PROJECT

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ÉLECTRICITÉ DU LAOS

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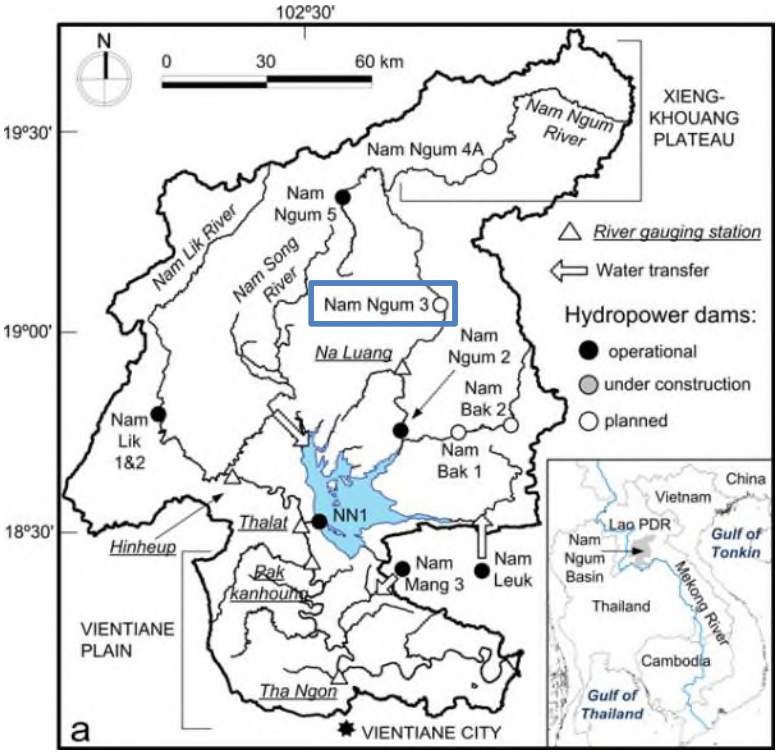
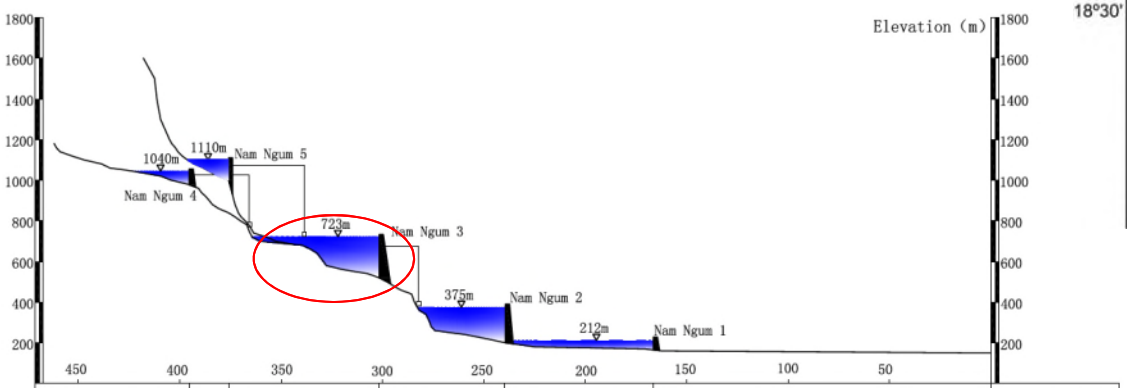
Project characteristics

Nam Ngum River

- Tributary of Mekong River
- Watershed area : 16 640 km²
- 3 operational HPPs (Nam Ngum 1, 2 & 5)
- 2 projects under construction (Nam Ngum 3 & 4)





NN4		NN5	NN3	NN2	NN1	Name of HPPs
395		376	302	240	166	Distance from Mekong River (km)
986		1020	520	200	165	Elevation (m)

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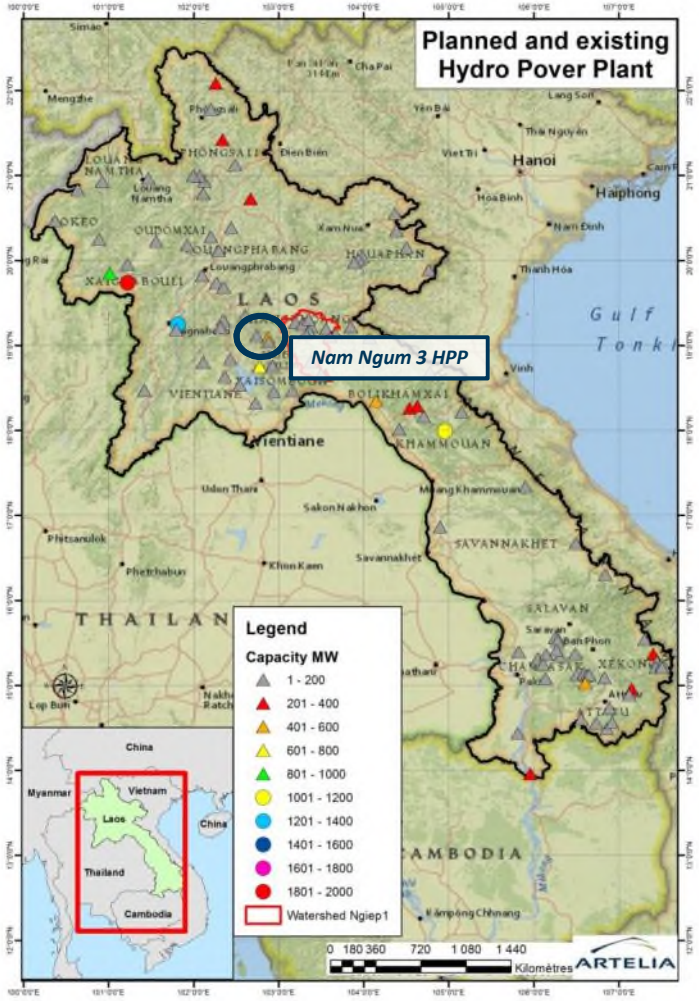
Project characteristics

General information

- **Developer :** Electricité Du Laos (EDL) – Lao PDR
- **Employer's Representative :** ARTELIA – France
- **EPC contractor :** SINOHYDRO – China

- **Location**
  - Nam Ngum River
  - Long Cheng city
  - 50 km upstream of Nam Ngum 2 HPP

- **General project features**
  - Installed capacity = 480 MW
  - Maximum head = 340 m
  - Average annual energy = 2 345 GWh
  - Reservoir volume = 1 400 Mm³ (at FSL)
  - Catchment area = 3 913 km²



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Project characteristics

Main characteristics

- Dam
  - Concrete Faced Rock Dam (CFRD)
  - 212 m high
- Spillway
  - 3 radial gates (W=14.5 m; H=18 m)
  - 6,472 m3/s (design flood – water level at 723)
  - 10,024 m3/s (check flood – water level at 728.81)

Downstream view of the dam and spillway

- Headrace tunnel
  - 10,554 m long
  - Capacity of 180 m3/s
  - Horseshoe shaped with concrete lining
- Surge shaft
  - 240 m high
  - 15 m inner diameter
- Pressure shaft
  - 1623 m long conduit
- Powerhouse
  - Open air powerhouse
  - Francis turbine
  - 3x160 MW

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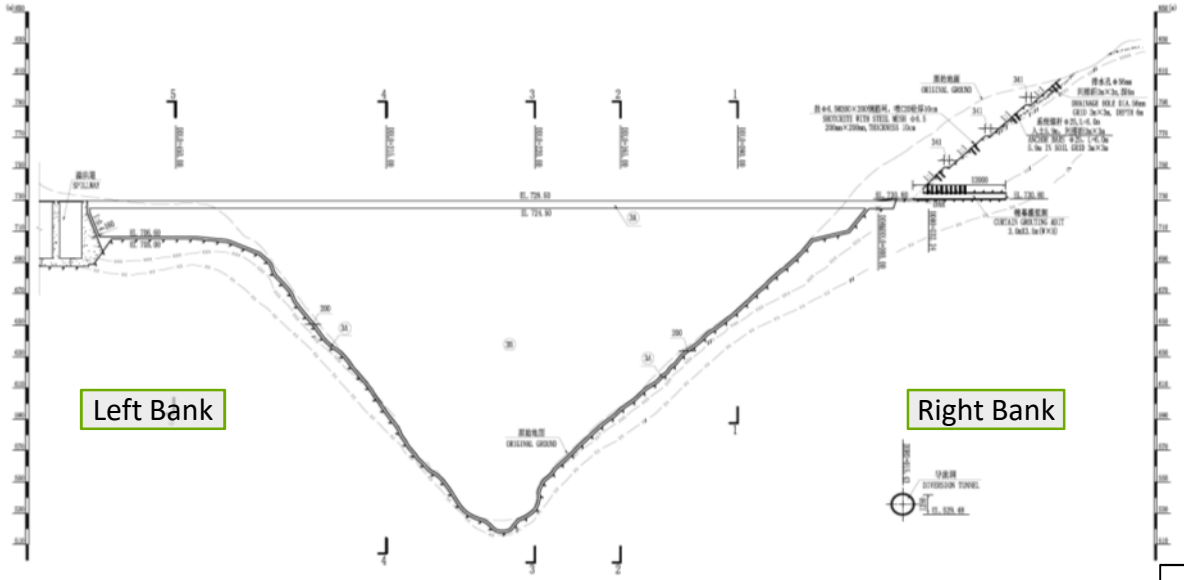
Dam Design

Valley characteristics and geology

- Characteristics of the valley
  - River valley is relatively a narrow gorge
  - River banks characterized by prominent east-west trending ridges

- Geology
  - Soil cover : alluviums and colluviums
  - Rock surface : Sandstones and Conglomerates (Devonian clastic rocks)

Rock foundation



Section at dam axis

Thin fault / schist band

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Dam Design

Nam Ngum river valley at dam site

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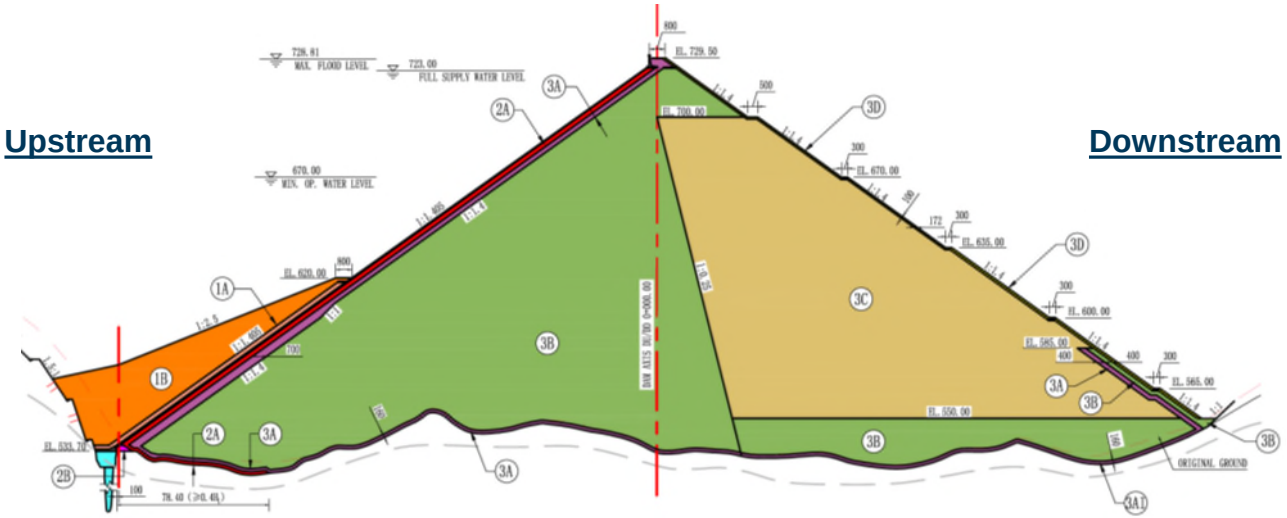
Dam Design

Dam geometry

- Maximum height above foundation = 212 m
- Crest length = 518 m
- Crest width = 8 m
- Slopes
  - Upstream : 1V : 1.4 H
  - Downstream : 1V : 1.4 H between two berms (1 V : 1.5 H equivalent slope)
- Dam backfill volume = about 15 Mm³
- Concrete face slab surface = 130,000 m²



Dam section

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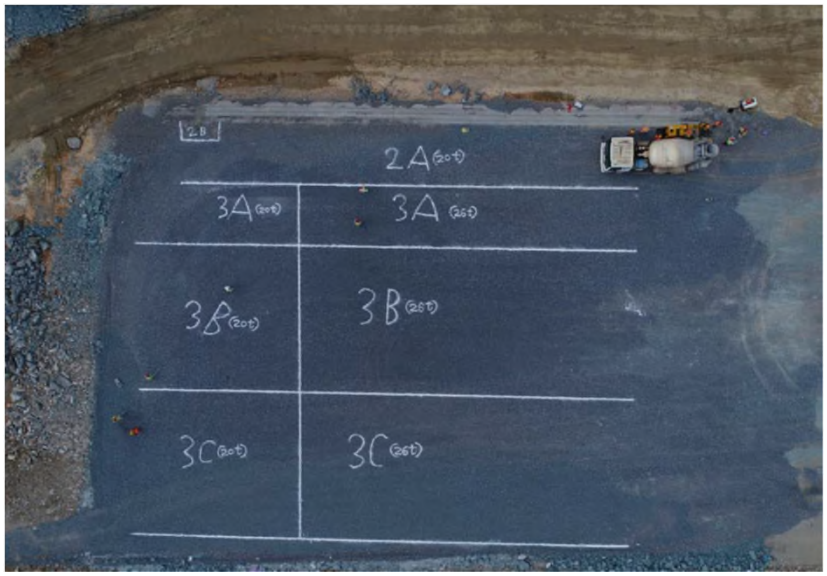
Dam Design

Dam materials – Trial Panels

- Gneiss Quarry



- Trial Panel

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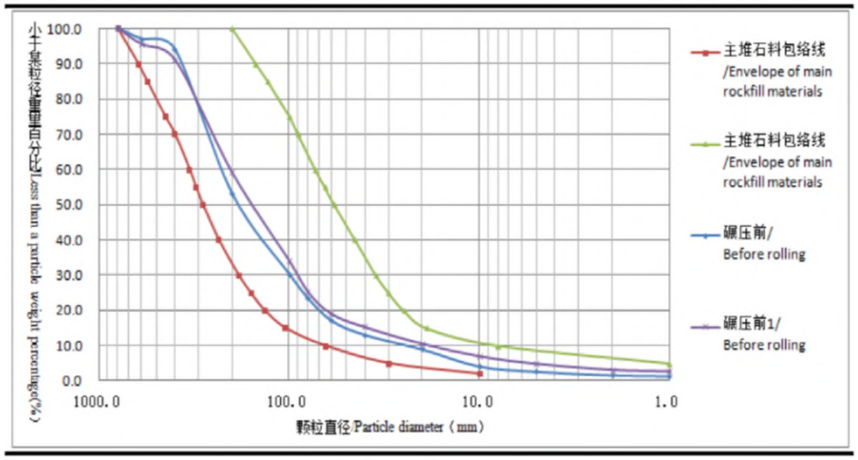
Dam Design

Dam materials – Trial Panels

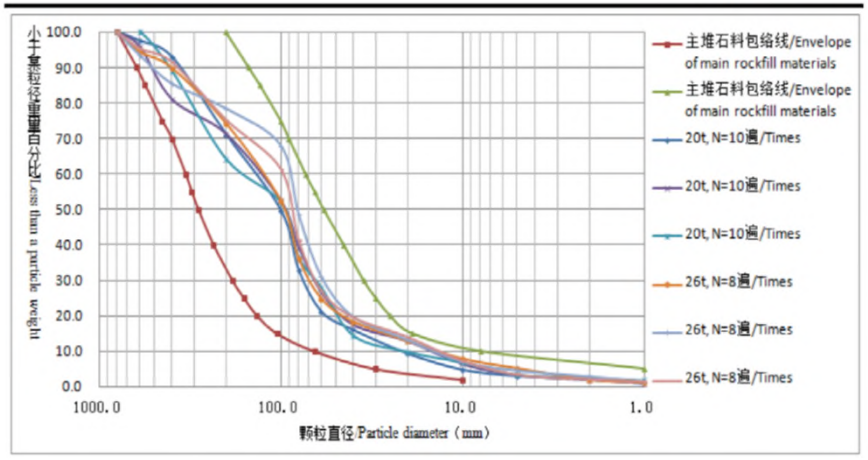
Particle gradation curve of main rockfill materials before rolling

图/picture 12.8.1



Particle gradation curve of main rockfill materials after rolling

图/picture 12.8.2



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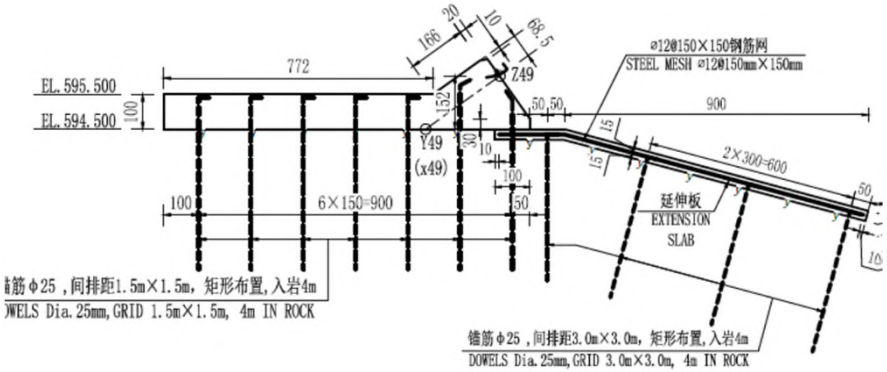
Plinth Design

- Variable thickness : 0,60 to 1,00 m
- Width depending on the quality of rock and allowable hydraulic gradient (20 to 5)
- Where necessary, an extension slab is added downstream of the plinth to increase the hydaulic path,
- The plinth is anchored to the foundation through 25mm anchor bars
- Consolidation grouting to 8m depth
- Reinforcement
  - One layer of two-way steel bars
  - Ratio of 0.4%



Concrete Face Design

Face slab design

- Variable thickness of the concrete face slab function of the vertical distance H between the considered altitude and the face slab top
  - Both sides : t = 0.3 + 0.003 H, in m
  - Central section : t = 0.5 + 0.003H
- Reinforcement
  - One layer of two-way steel bars
  - Ratio of 0.4%
- 3 types of joint
  - 2 compression joint types with variable thick space (24 and 50 mm)
  - 1 tensile joint type

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Feedback

Nam Ngum 3 dam versus similar dams

- Valley shape factor (A/H^2) is around 3.1
- Past experience in CFRD dams shows that in such narrow valleys, the concrete facing is vulnerable to cracking due to high compression stress. This is attributed to stress arching effect across the abutments.

Examples of CFRD dams which have experienced severe compression cracking are:

- Campos Novos (Brazil) : H = 202m, A/H^2 = 2.6
- Barra Grande (Brazil) : H = 194m, A/H^2 = 2.9
- Mohale (Lesotho) : H = 145m, A/H^2 = 4

Barra Grande

Campos Novos

Mohale

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Feedback

Nam Ngum 3 dam versus similar dams

- On the other hand, other dams with similar characteristics which have undergone extensive analysis and which design has been adapted to take account of rockfill deformations, have been impounded successfully, for example:
  - Nam Ngum 2 (Laos) : H = 182m, $A/H^2 = 2.7$
  - Bakun (Malaysia) : H = 205m, $A/H^2 = 3$

- In the design process, attention has to be paid to
  - The rockfill deformations and subsequent concrete face deformations
  - Stress pattern due to the impoundment

- The concrete face slab constructive details have to be adapted to stress and deformation patterns

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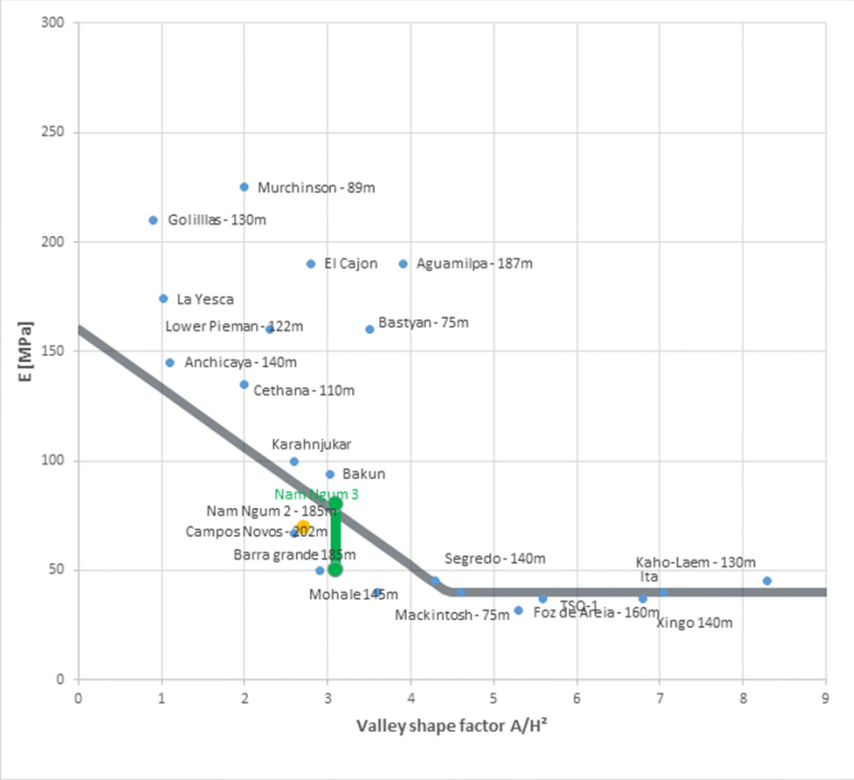
Feedback

Nam Ngum 3 dam versus similar dams

- Deformation modulus* is estimated between 50 MPa and 80 MPa



Graph of deformation modulus vs. Valley shape factor (after Pinto)

** To be estimate more accurately through a back analysis using monitoring results during the backfilling*

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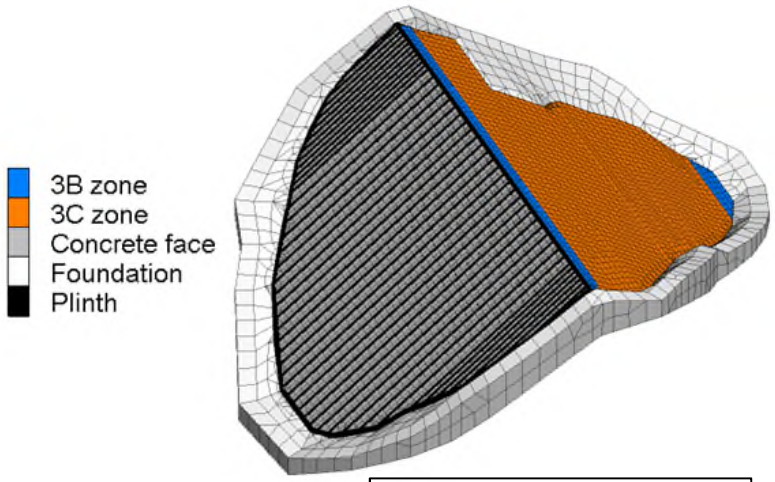
Numerical model

ARTELIA counter calculations

- 3D numerical analyses of the dam with objective :

To check the design and construction provisions proposed by the Contractor in order to avoid damages to the facing slab

- Foundation is modeled to check any possible relative shear displacement between the rockfill materials and the bedrock
- Joints are modeled:
  - Bedrock / Rockfill material
  - Concrete face / Cushion layer
  - Plinth / Concrete face
  - Vertical joints of the concrete face



ARTELIA 3D numerical model

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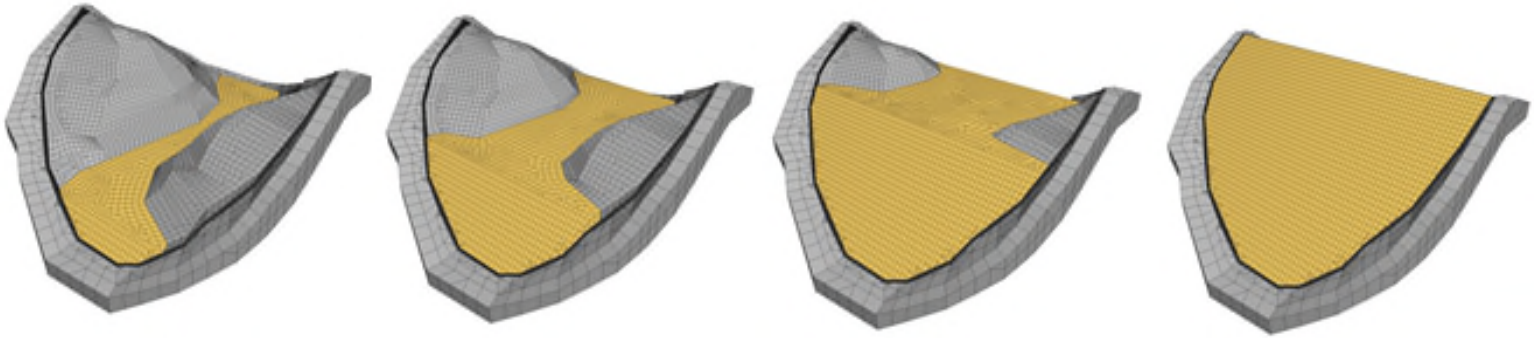
Numerical model

Capacities and targets of ARTELIA numerical model

- Simulation of the initial opening of the vertical compression joints of the concrete face (50 mm and 24 mm)

  A compressive stress is generated only after the closure of the initial opening

- A staged construction of the dam is considered by means of subsequent layers of rockfill



- A Plastic-Hardening Constitutive law is used

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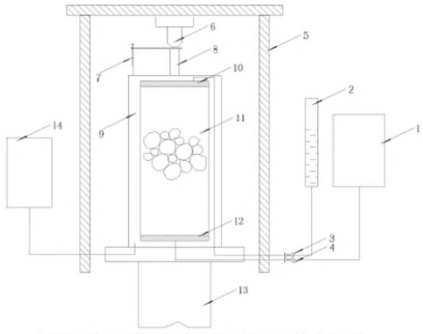
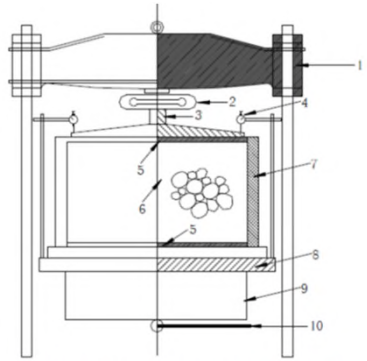
Numerical model

Calibration

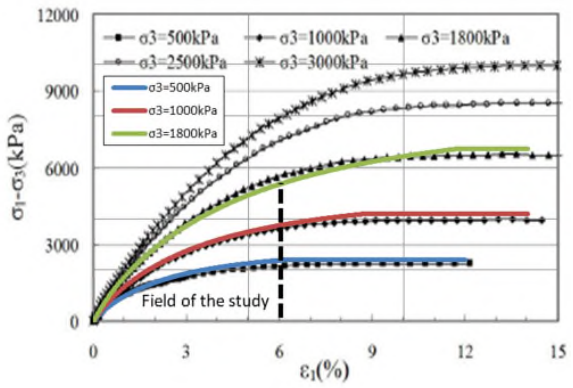
- Laboratory testing (NHRI – Nanjing Hydraulic Research Institute):
  - Large triaxial tests
  - Large oedometer tests



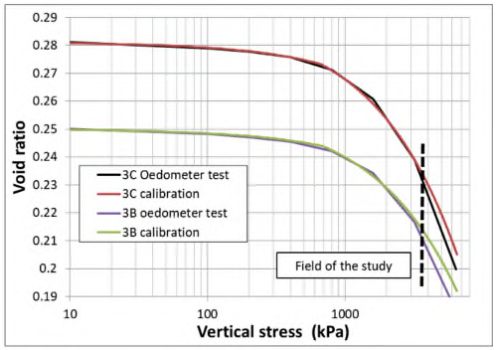
1.water supply system for saturation;2.measuring system of volume strain;
3.upper draw off valve;4.saturation valve;
5.frame for loading;6.pressure sensor;
7.displacement sensor;8.piston;9.pressure chamber;
10.upper perforated plate;11.sample;12.perforated plate at bottom;
13.fluid pressure system;14.confining pressure system



1. frame for loading;2.compression gauge;3.shaft for pressure deliver;
4.displacement sensor;5.porous disc;
6.sample;7.water channel for saturation;8.supporting base;
9.oil press;10.to oil hydraulic system and constant pressure system



Triaxial - shear



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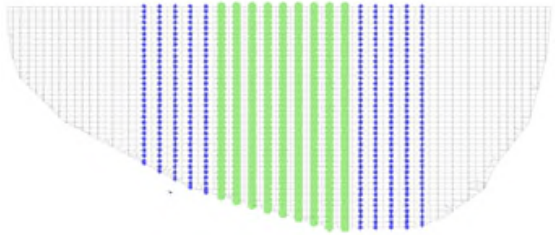
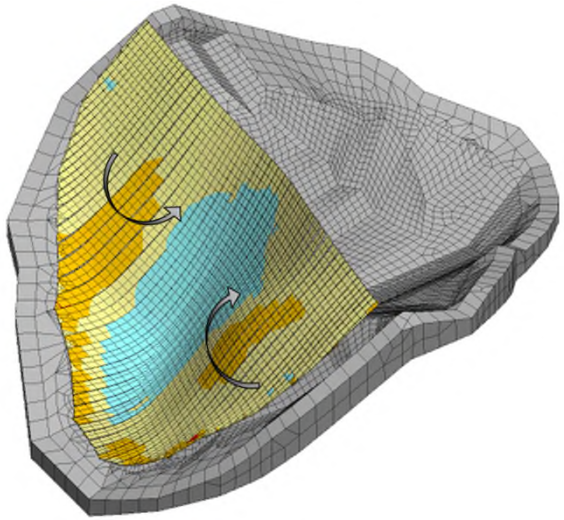
Numerical model

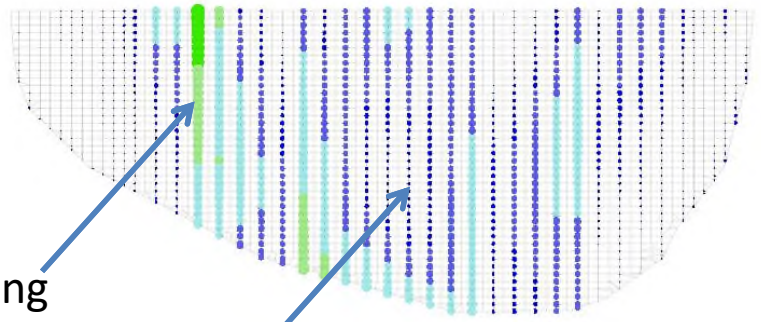
Results



Joint opening (cm)
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6

Initial state

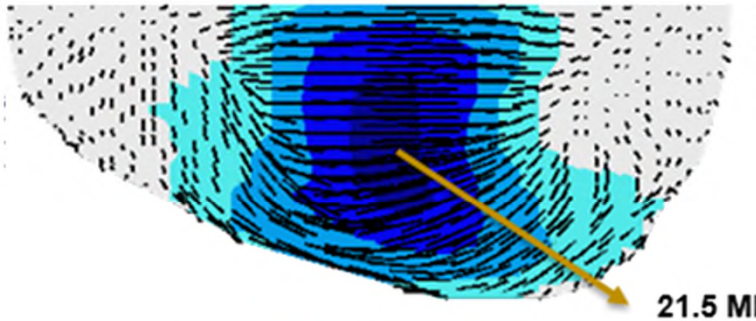




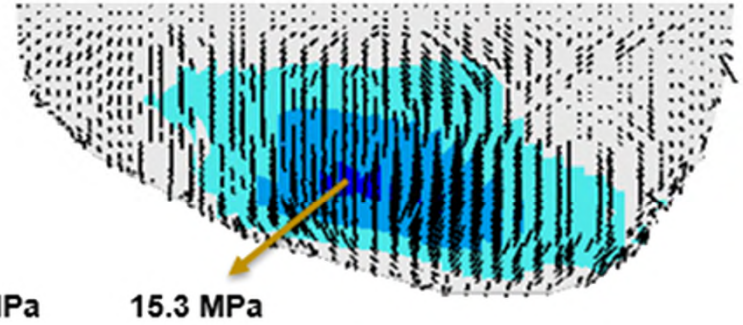
Further opening

Closing

Full supply level



21.5 MPa



15.3 MPa

Compression Principal Stress
1.5000E+07
1.0000E+07
5.0000E+06
0.0000E+00
-5.0000E+06
-1.0000E+07
-1.5000E+07
-2.0000E+07

Without compression joints

With compression joints

Full supply level

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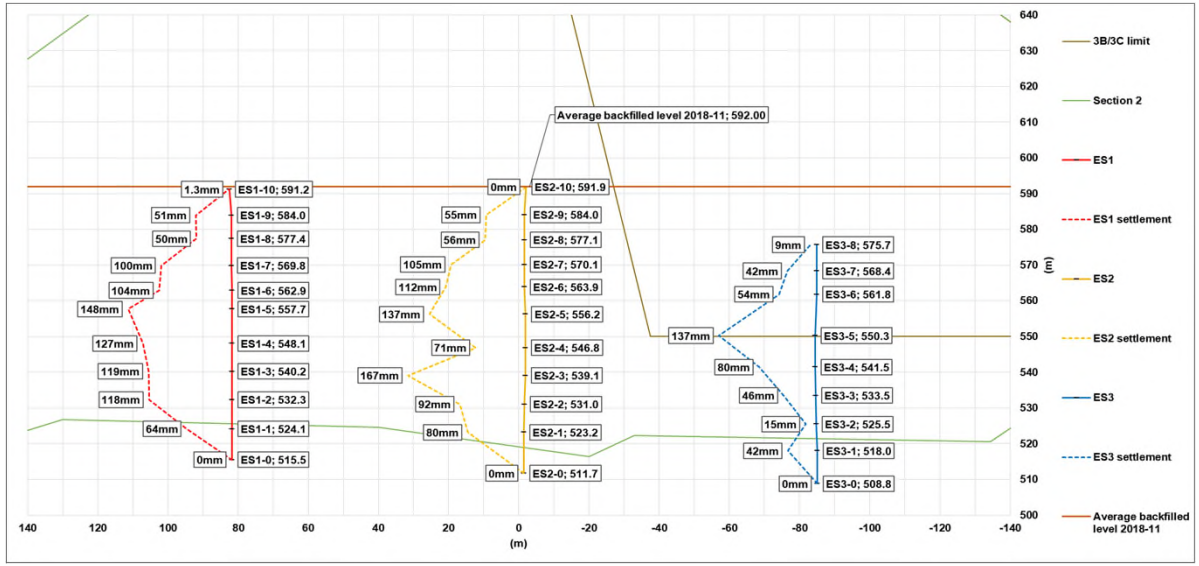
Numerical Model
Back analysis

- Dam monitoring during construction :
  - Settlement tubes (Electromagnetic)
  - Hydraulic Settlement level system
  - Horizontal displacements (extensometers)



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Summary of constructive arrangements for the face slab

- Provision of compression joints in the central part of the slab
- Increase the slab thickness by 20 cm in the central part of the dam
- Reduce the friction between the slab and the extruded concrete by applying an asphaltic emulsion
- Add reinforcement where necessary as shown by the numerical model
- Add of a horizontal contraction joint (under discussion)
- Sawing of the extruded curb behind the compression joints (under discussion)
- Construction of the face slab in 2 stages

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Photos

Upstream and downstream face

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Photos

Backfill compaction

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Photos

Extruded concrete

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Photos

Plinth

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Thank you for your attention

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